Cloud-based Exploration of Complex Ecosystems for Science, Education and Entertainment

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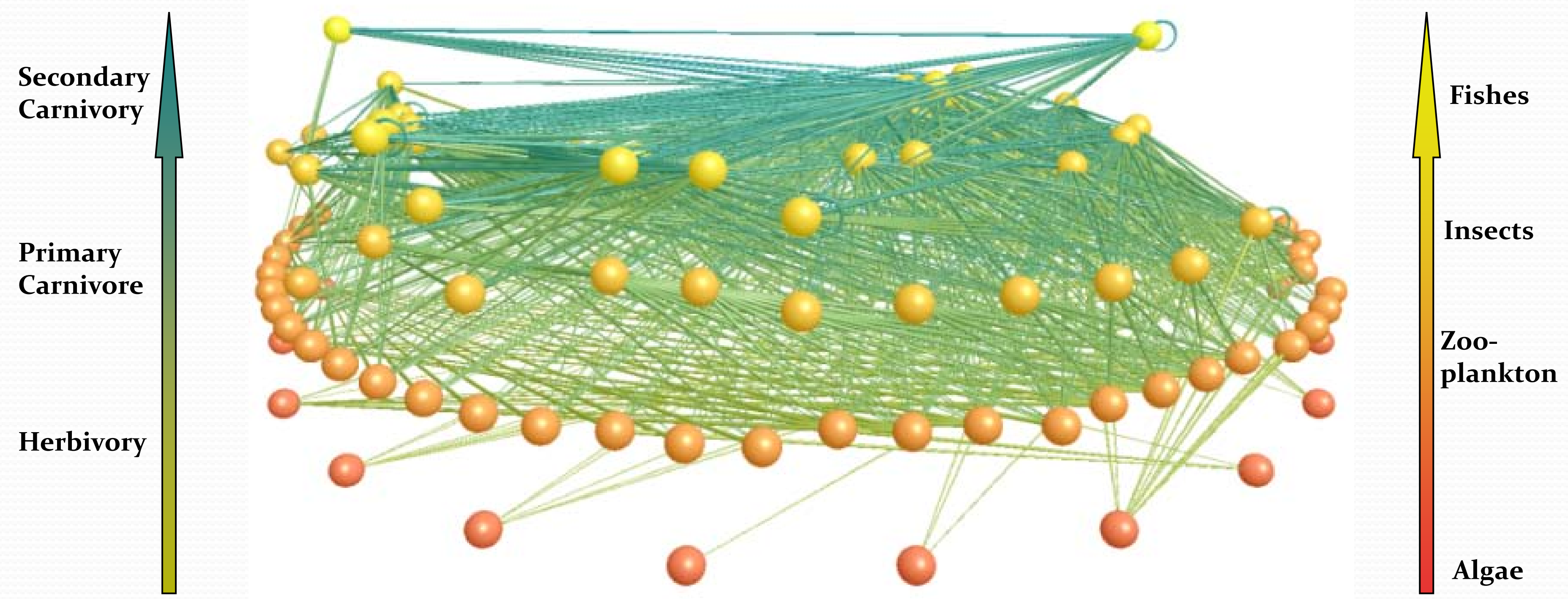
Rich J. Williams

Ecosystems: Complex Ecological Networks

Little Rock Lake Food Web: 92 Species (S) & 997 Links (L)

Connectance (C) = L / S^2

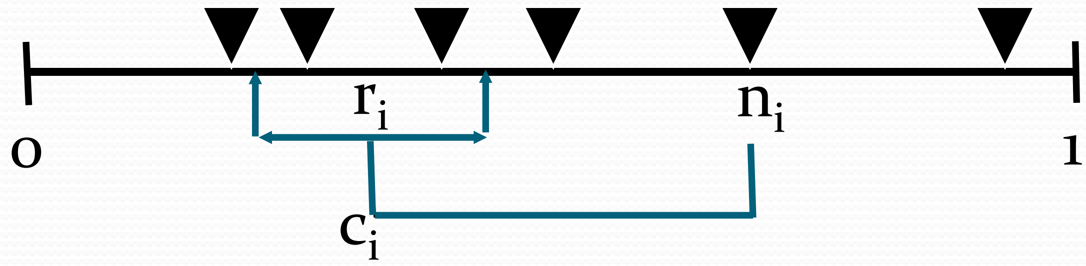


Link Color indicates Type of Feeding Link

Node Color indicates Trophic Level of Taxa

Martinez 1991 *Ecological Monographs*

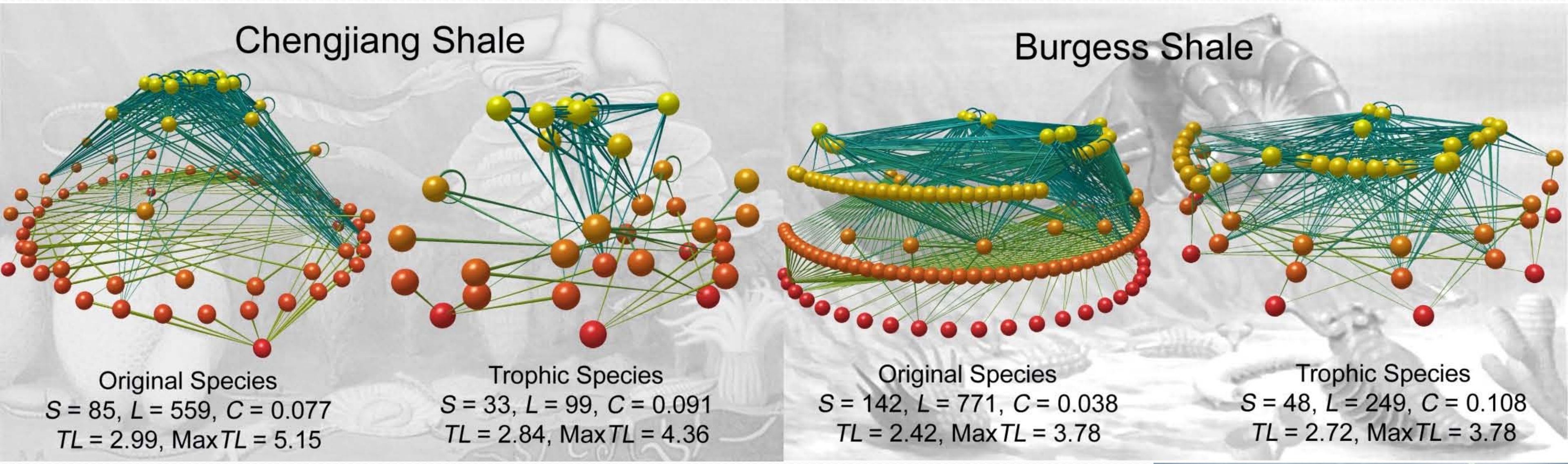
Niche Model: *S* & *C* inputs



- Rule 1: Each of *S* species gets uniformly random n_i
  - $0 < n_i < 1$
- Rule 2: Each S gets assigned a Random feeding range r_i
  - $0 \leq r_i \leq 1$; beta function mean of $2C$ multiplied by n_i
- Rule 3: Range is placed: uniformly random center: c_i
  - $r_i/2 < c_i < n_i$

Williams and Martinez 2000 *Nature*

Paleofoodwebs



Compilation and Network Analyses of Cambrian Food Webs
Dunne, Williams, Martinez, Wood & Erwin et al. 2008
PLoS Biology

Niche Model

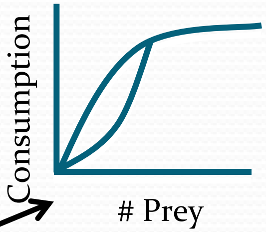
- Generates Realistic Network Architectures
  - Effects of S and C on network structure

- Provides a Benchmark

- Scaffolding for Network Dynamics

Bioenergetic Dynamics

Handling
Attack
Interference



$$B_i'(t) = G_i(B) - x_i B_i(t) + \sum_{j=1}^{n}\left(\left(x_i y_{ij} \alpha_{ij} F_{ij}(B) B_i(t) - x_j y_{ji} \alpha_{ji} F_{ji}(B) B_j(t)\right) / e_{ji}\right)$$

Rate of change in biomass = Production rate of basal spp. − Loss of biomass to metabolism + (Gain of biomass from resource spp. − Loss of biomass to consumer spp.)

Time evolution of species' biomasses in a food web result from:

- Basal species grow via a carrying capacity, resource competition, or Tilman/Huisman models
- Other species grow according to feeding rates and assimilation efficiencies (e_{ji})
- All species lose energy due to metabolism (x_i) and consumption
- Functional responses determine how consumption rates vary
- Rates of production and metabolism (x_i) scale with body size
- Metabolism specific maximum consumption rate (y_{ij}) scales with body type

Yodzis & Innes (1992) Body size and consumer-resource dynamics. *Amer. Nat*.
Williams & Martinez (2004) Stabilization of chaotic and non-permanent food web dynamics. *Eur. Phys. J. B*

Application: Species loss

2009 *PNAS* 106:187-191

Simple prediction of interaction strengths in complex food webs

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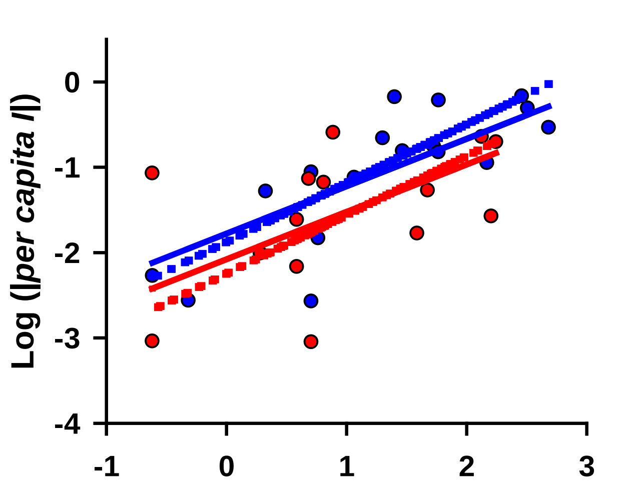


predicted
High *R* Biomass
Low *R* Biomass

observed
High *R* Biomass
Low *R* Biomass

Application: Dynamics of a Specific System

Lake Constance

Germany, Austria, Switzerland

Rich empirical data:

S = 24
Trophic network data
Weekly biomass & productivity data, 10-20 yrs
Metabolic data & body size

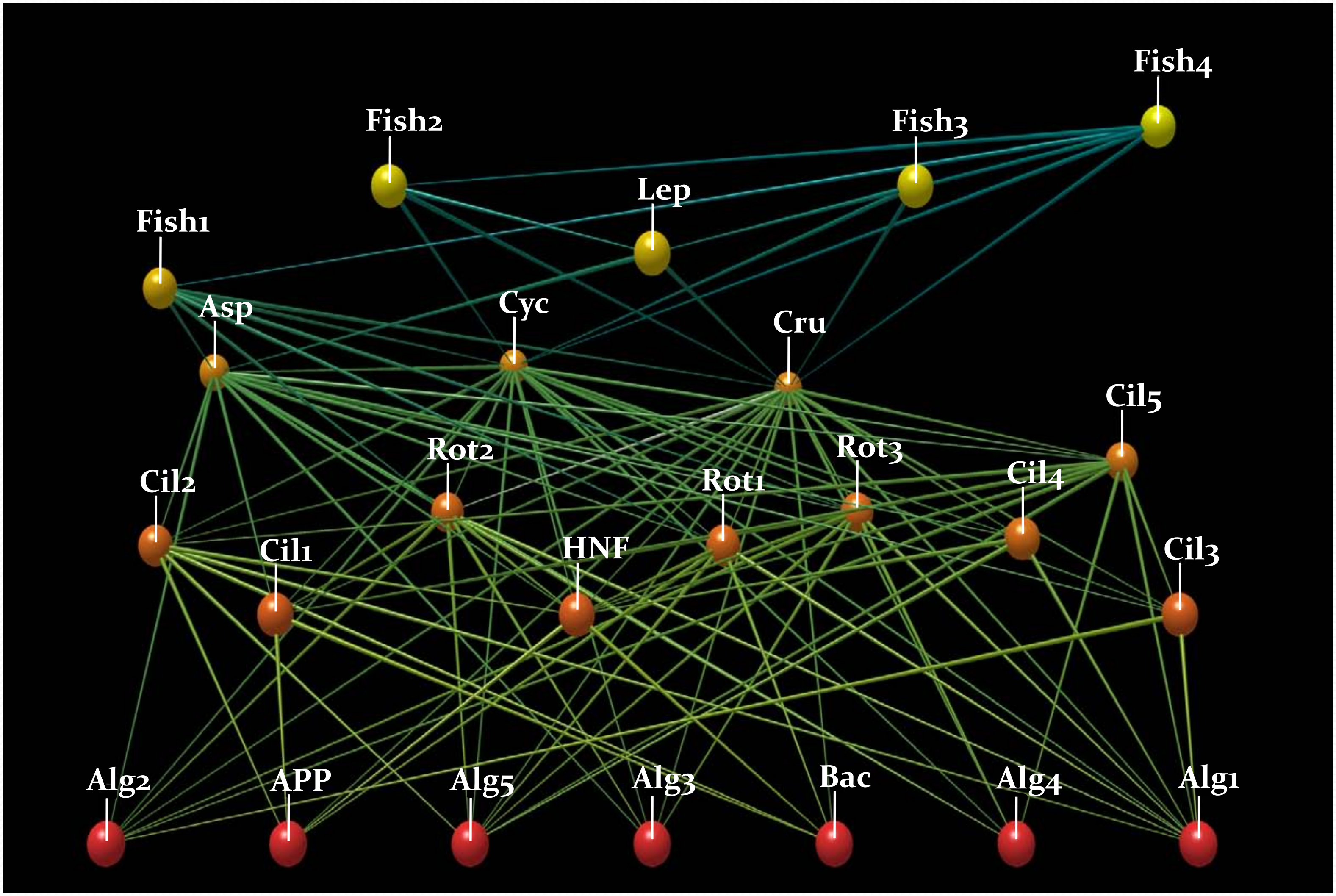
Run generic to specific versions of the ATN model and compare output to biomass time series data

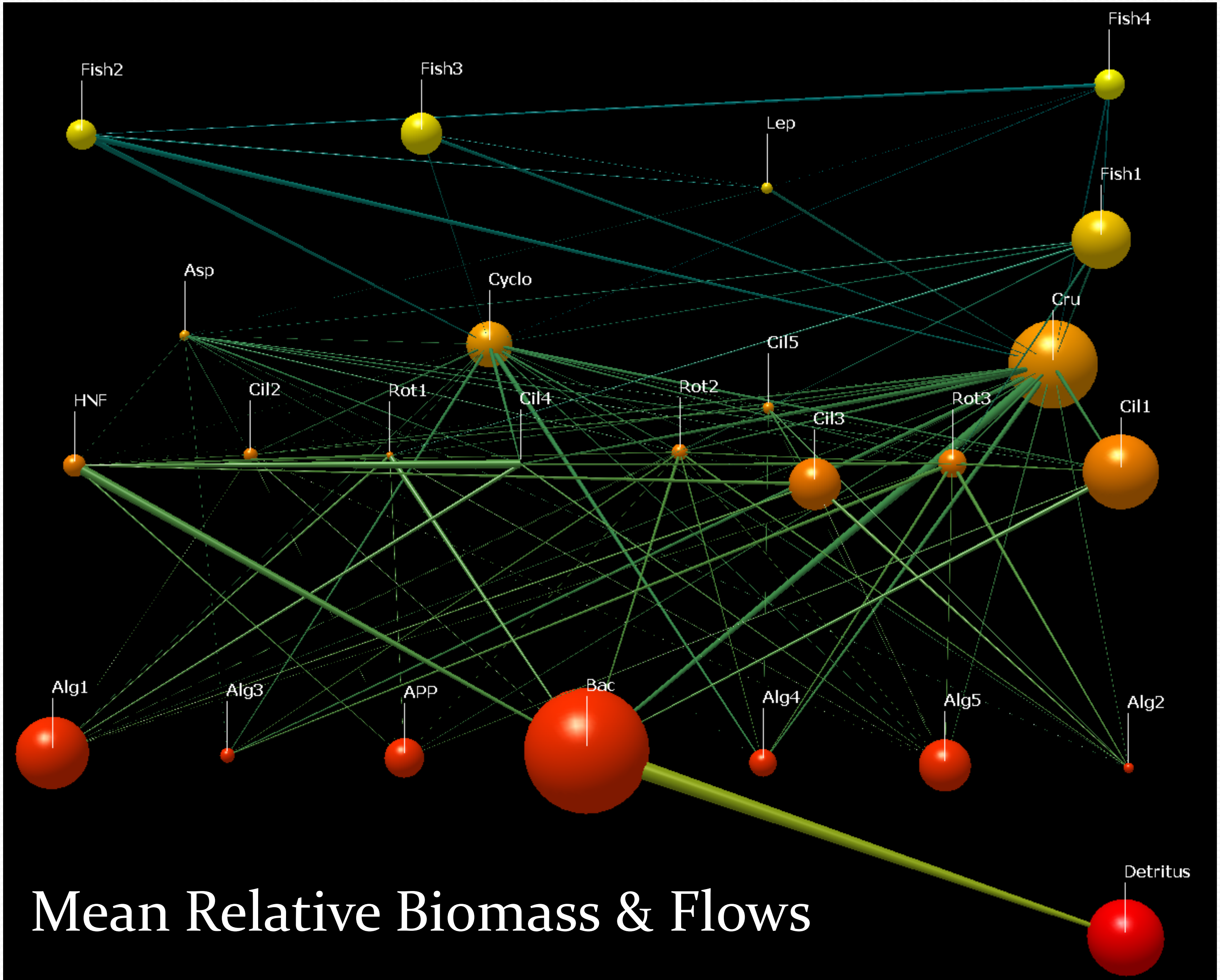
(i.e., idealized system, generalized lake pelagic system, highly constrained system)

Boit, Martinez, Williams & Gaedke (2012) Mechanistic Theory and Modeling of Lack Constance. *Ecology Letters*

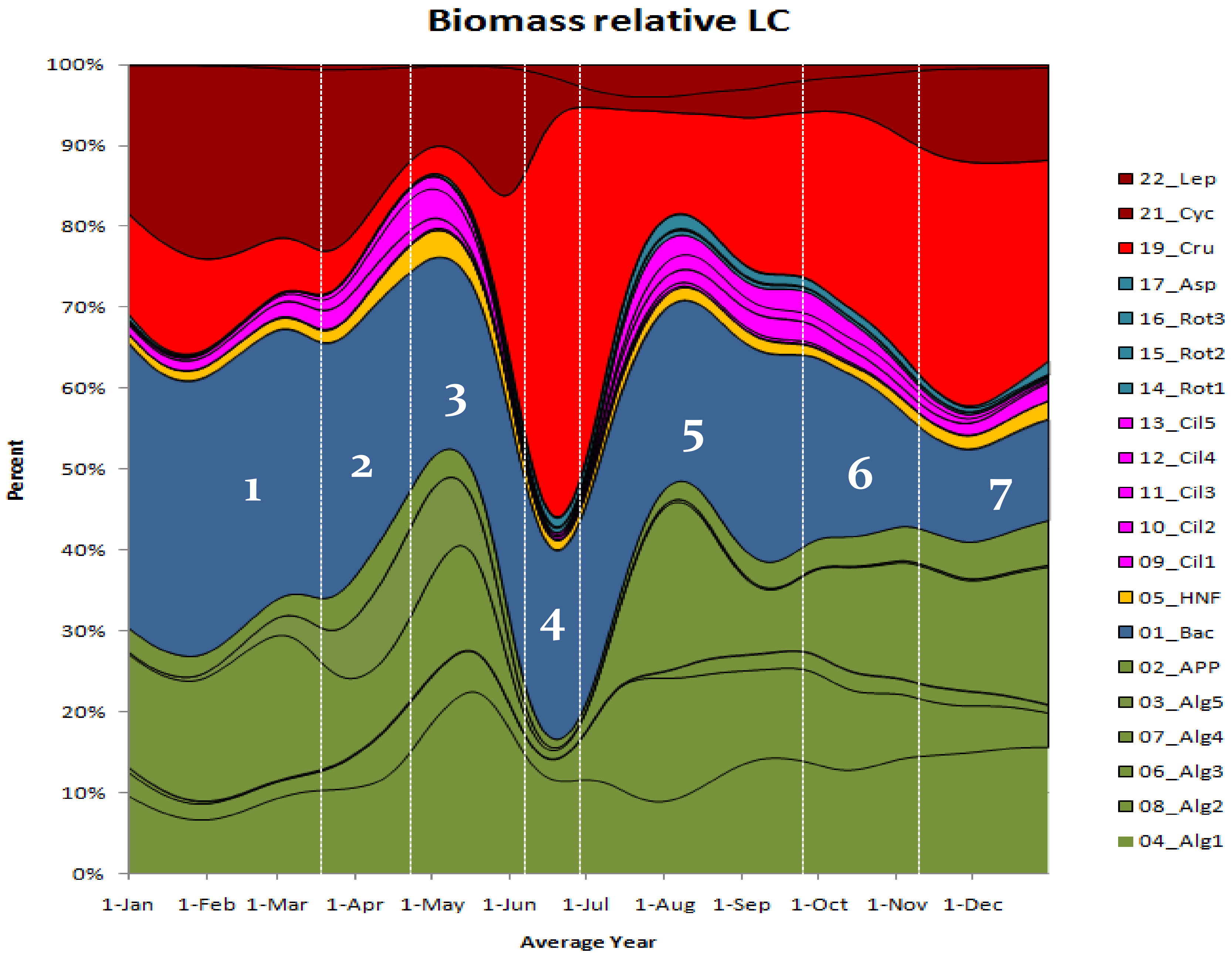
Lake Constance

- 24 Species, 104 Links, Conectance = 0.18



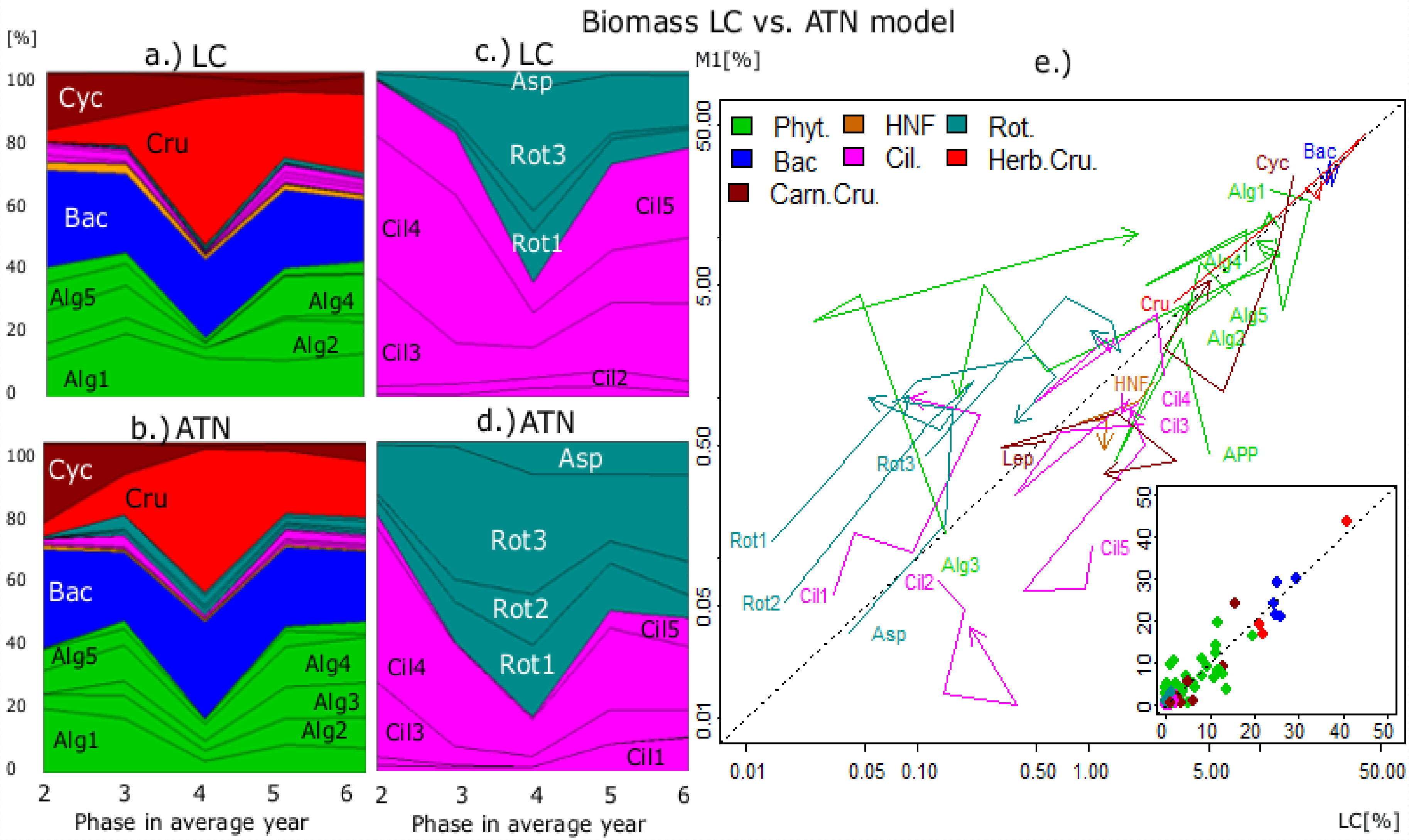


Mean Relative Biomass & Flows



Biomass relative LC
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent
1
2
3
4
5
6
7
1-Jan
1-Feb
1-Mar
1-Apr
1-May
1-Jun
1-Jul
1-Aug
1-Sep
1-Oct
1-Nov
1-Dec
Average Year
22_Lep
21_Cyc
19_Cru
17_Asp
16_Rot3
15_Rot2
14_Rot1
13_Cil5
12_Cil4
11_Cil3
10_Cil2
09_Cil1
05_HNF
01_Bac
02_APP
03_Alg5
07_Alg4
06_Alg3
08_Alg2
04_Alg1

Lake Constance Biomass: Model-Data Similarity = 0.82

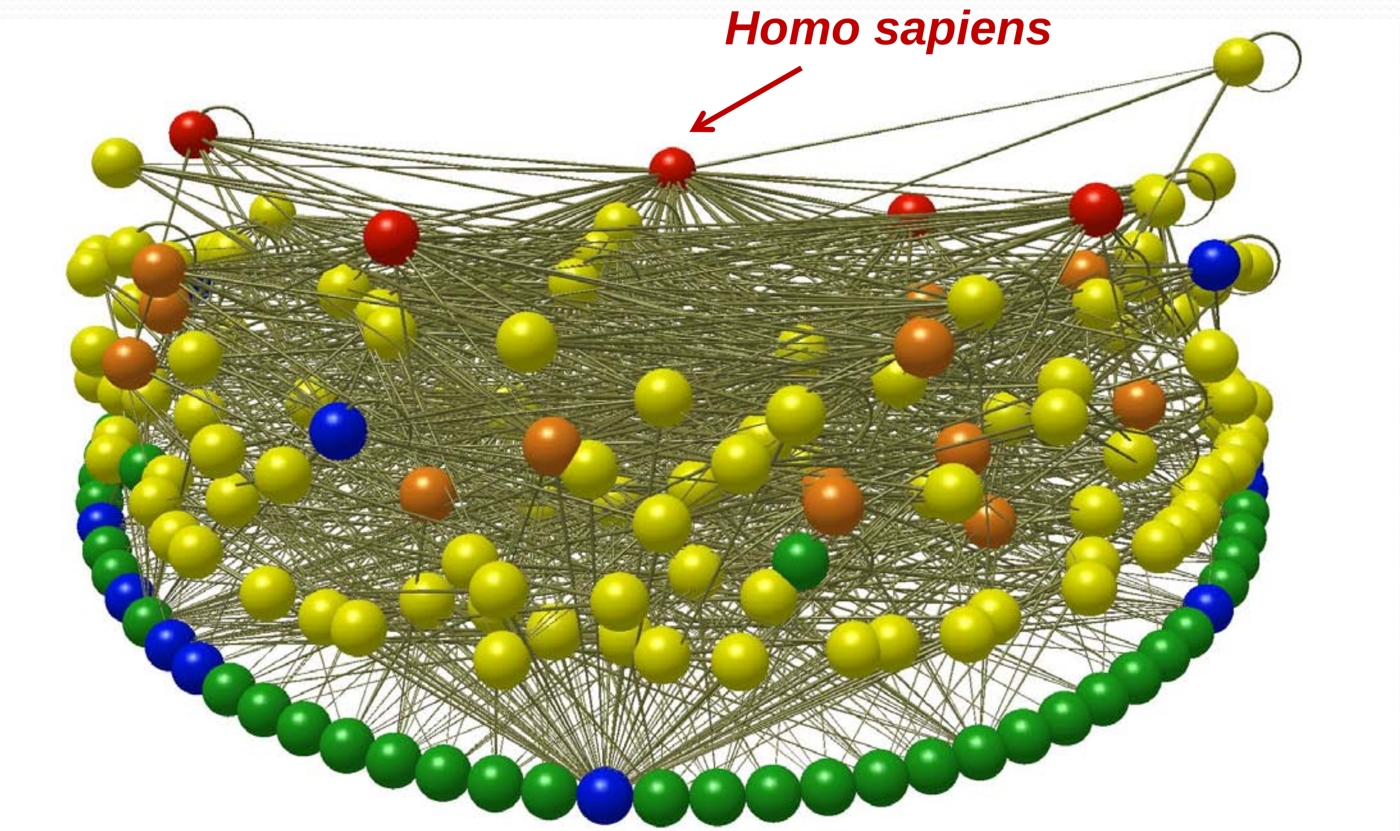


Ecological Forecasting

- Parameterize Network Model for System of Interest
  - Network Structure
  - Body Size and Type
- Tune Parameters to Historical Record
- Update Model with Realtime Data
- Continue machine learning

Forecasting Example: Humans

- Coupled Human-Natural Networks
- Aleuts on the Sanak Archipeligo



Martinez, Tonin, Bauer, Rael, Singh, Yoon, Yoon & Dunne *AAAI2012*

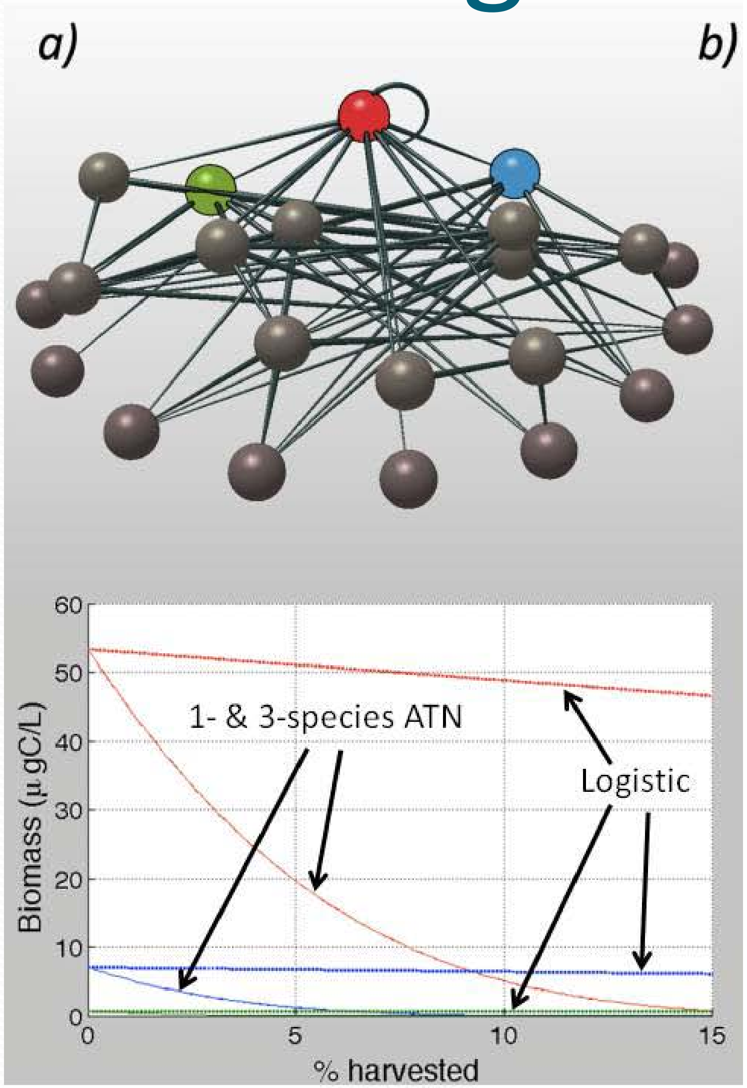
Forecasting Example: Fisheries

- $\dot{E} = \mu\,(pqB_i - c_o)\,E$
  - E is fishing effort for species I
  - p is the price per unit catch
  - q is the "catchability coefficient",
  - B_i is the biomass density of exploited species i,
  - c_o is the cost per unit effort,
  - μ is market openness

  - E increases with profit
  - E decreases with loss

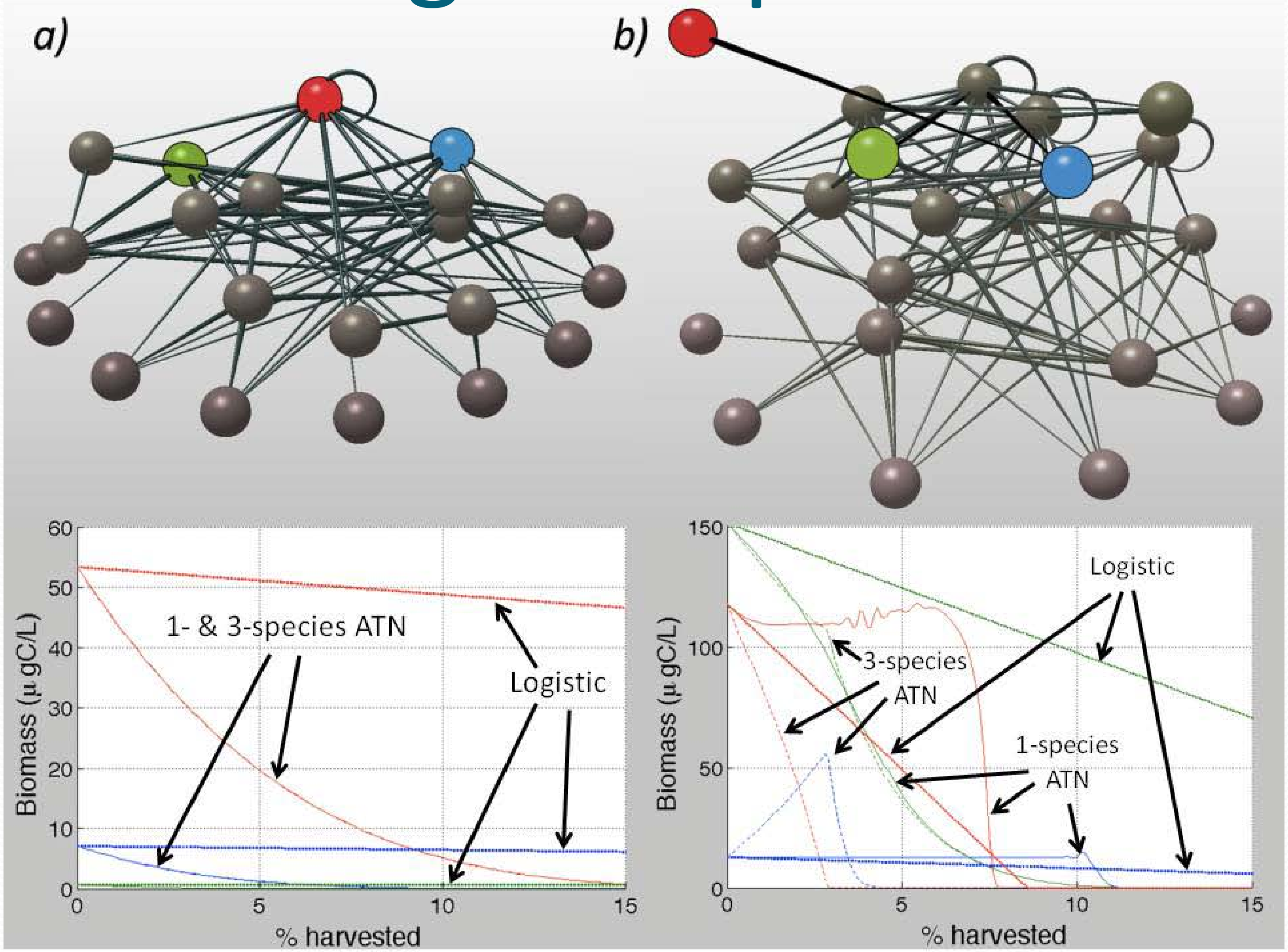
Martinez, Tonin, Bauer, Rael, Singh, Yoon, Yoon & Dunne *AAAI2012*

Forecasting Example: Fisheries



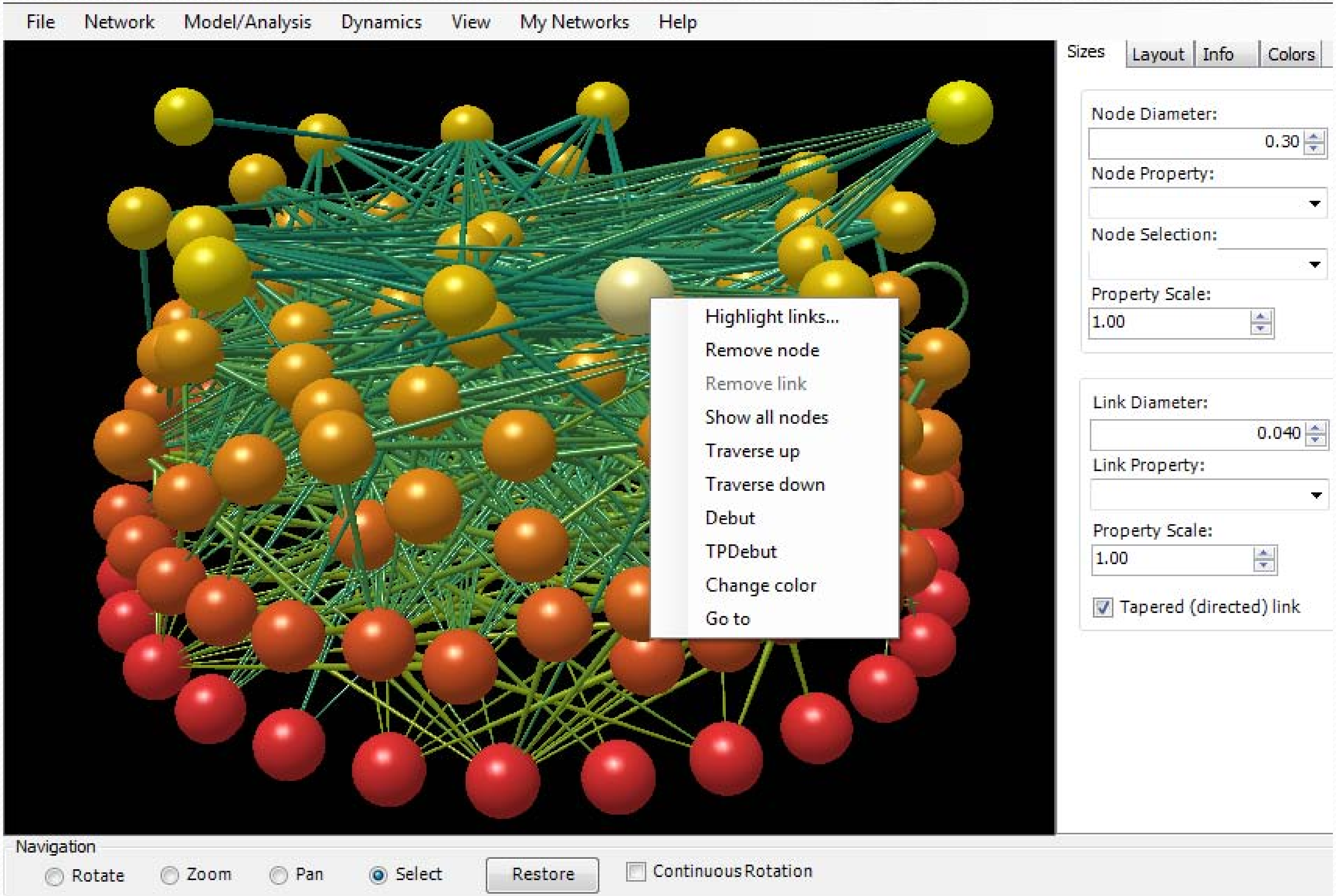
Martinez, Tonin, Bauer, Rael, Singh, Yoon, Yoon & Dunne ***AAAI2012***

Forecasting Example: Fisheries

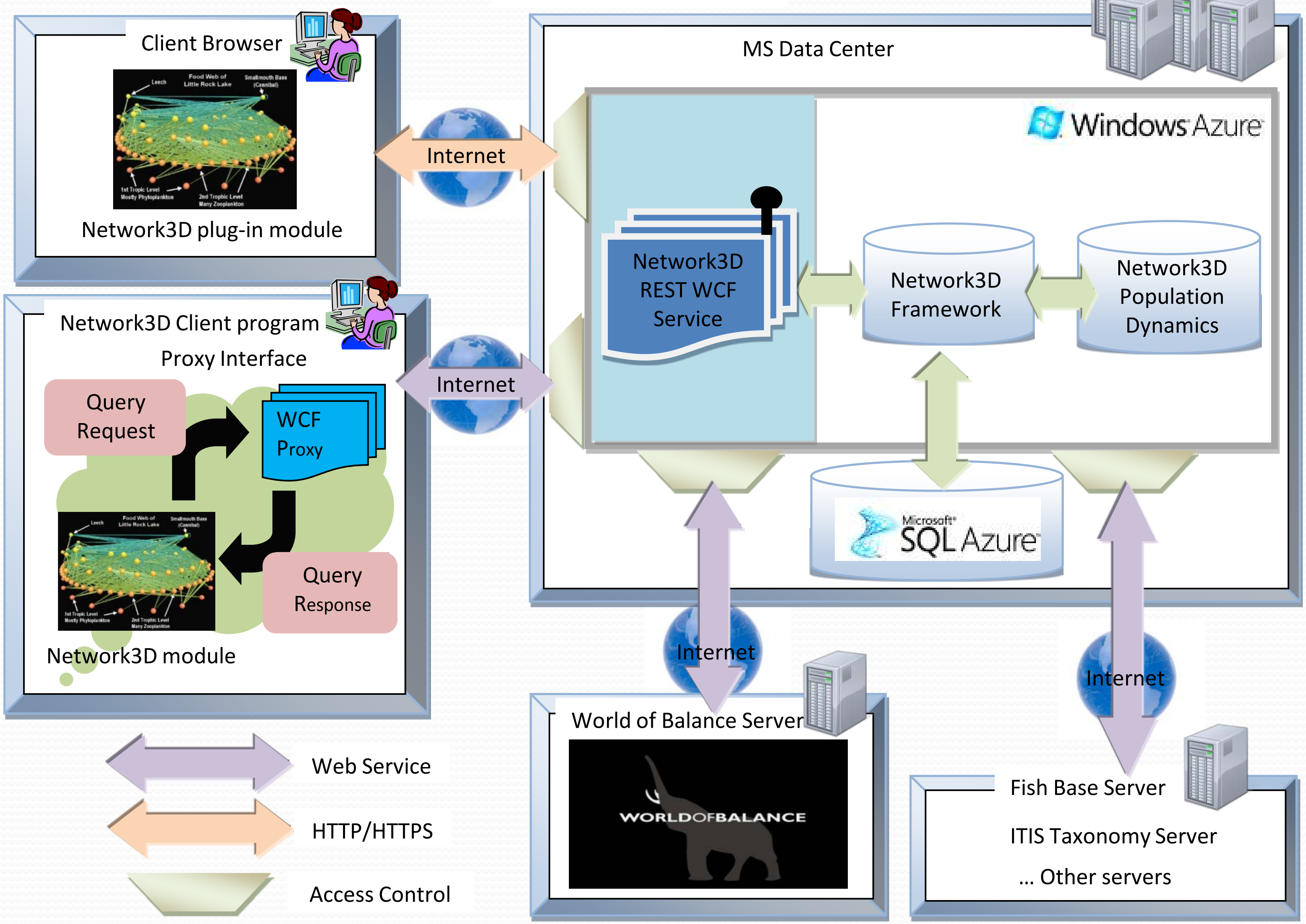


Martinez, Tonin, Bauer, Rael, Singh, Yoon, Yoon & Dunne ***AAAI2012***

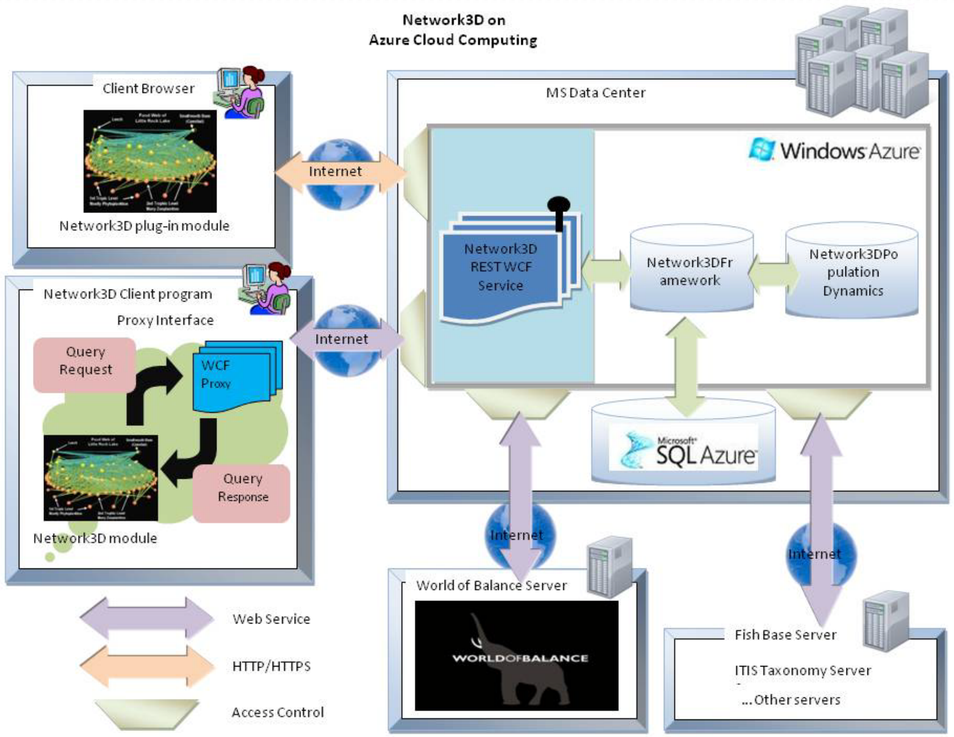
Cyberinfrastructure: Network3D



Network3D on Azure Cloud Computing

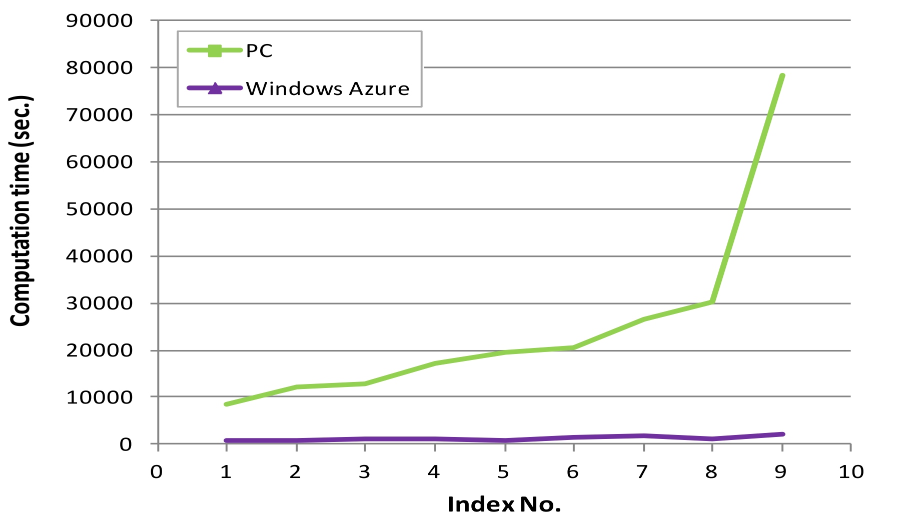


Cyberinfrastructure for Ecological Networks



- Application as a Service
- Ease
  - Network3D written in C#
- Scalable
  - Azure Cloud
- Accessible
  - Web Services
  - Browser Client
  - Data
  - Game (WoB)

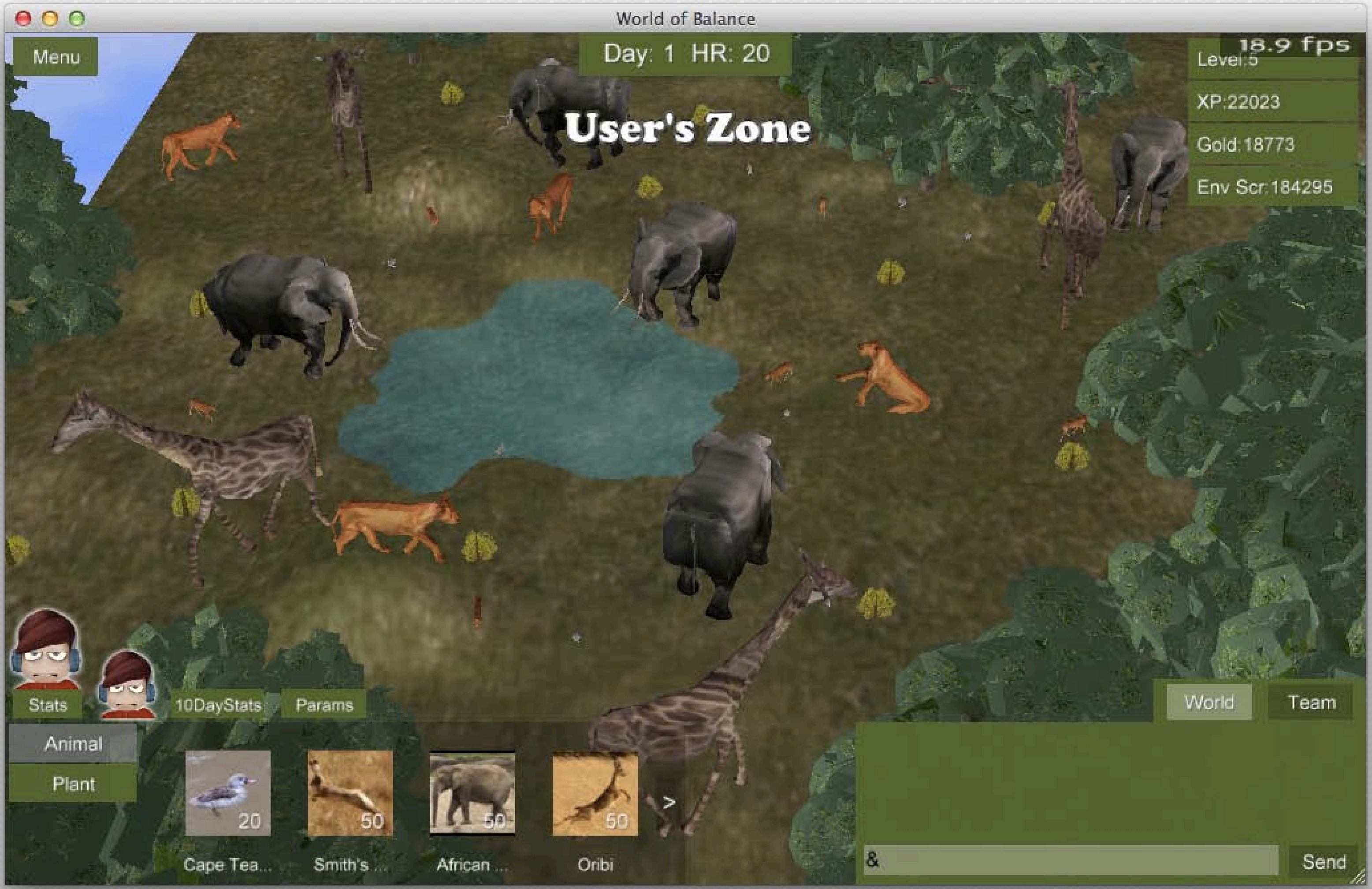
Network3D on Azure



Index No.	Food web	Node No.	Link No.
1	St.Martin Island	44	218
2	Coachella	30	290
3	Glass	75	113
4	Bridge Brook Lake	75	553
5	Flack	48	702
6	Hawkins	87	126
7	Seregenti	86	547
8	Everglades	65	652
9	Elverde	156	1510

- Additional opportunities for parallel computing within Azure

WoB: World of Balance



WoB: World of Balance

- World of Balance YouTube Clip

Future: Cloud Enabled Exploration of Complex Ecological Networks

- Games and Research Simulations
  - Easy to conduct
  - Results Stored and Accessible
  - Computer Science

Future: Cloud Enabled Exploration of Complex Ecological Networks

- Integration with other Data
  - Empirical Observations (e.g., L. Constance, Fisheries)
  - Other simulations (e.g., Matlab)
  - Realtime observations (e.g., light and rain measures)

Future: Cloud Enabled Exploration of Complex Ecological Networks

- Solutions Obtained
  - Behavior, Stability and Robustness of Ecological Networks
  - Understanding and management of Human-Natural Networks
  - Social Networks/Public Appreciation of Ecosystems
    - Ecological and Economic Interdependence
    - One's own "place in the world"

Future: Cloud Enabled Exploration of Complex Ecological Networks

Games and Research Simulations
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Microsoft Research

Integration with other Data
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NSF

Solutions Obtained
- Behavior, Stability and Robustness of Ecological Networks
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